

4. MAJOR ACTIVITIES

The previous section outlined the science activities pursued in the Laboratory for Atmospheres. This section presents summary paragraphs of our major activities in measurements, field campaigns, data sets, data analysis, and modeling. In addition, we summarize the Laboratory's support for NOAA's remote sensing requirements. The section concludes with a listing of project scientists, and a description of interactions with other scientific groups.

4.1 Measurements

Studies of the atmospheres of Earth and the planets require a comprehensive set of observations, relying on instruments borne on spacecraft, aircraft, balloons, or those that are ground-based. Our instrument systems 1) provide information leading to basic understanding of atmospheric processes, and 2) serve as calibration references for satellite instrument validation.

Many of the Laboratory's activities involve developing concepts and designs for instrument systems for space-flight missions, and for balloon, aircraft, and ground-based observations. Airborne instruments provide critical *in situ* and remote measurements of atmospheric trace gases, aerosol, ozone, and cloud properties. Airborne instruments also serve as stepping-stones in the development of spaceborne instruments, and serve an important role in validating spacecraft instruments.

Table 4.1 shows the principal instruments that were built in the Laboratory, or for which a Laboratory scientist has had responsibility as Instrument Scientist. The instruments are grouped according to the scientific discipline each supports. Table 4.1 also indicates each instrument's deployment—in space, on aircraft, balloons, on the ground, or in the laboratory. In most cases, details are presented in a separate Laboratory technical publication, the *Instrument Systems Report*, NASA/TP-2005-212783, available on the Laboratory Web site. Exceptions are the Unmanned Aerial Vehicle (UAV) Radar (URAD), High-Altitude Imaging Wind and Rain Airborne Profiler (HIWRAP), and CO₂ lidar for which recent developments are described in Section 5.4.

Table 4.1: Principal instruments supporting scientific disciplines in the Laboratory for Atmospheres.

	Atmospheric Structure and Dynamics	Atmospheric Chemistry	Clouds and Radiation
Space		Total Ozone Mapping Spectrometer (TOMS)	
		Earth Polychromatic Imaging Camera (EPIC)	

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Aircraft/Balloon	ER-2 Doppler Radar (EDOP)	Airborne Raman Ozone, Temperature, and Aerosol Lidar (AROTAL)	Cloud Physics Lidar (CPL)
	Holographic Airborne	Raman Airborne Spectroscopic Lidar (RASL)	cloud THickness from Offbeam Returns (THOR) Lidar
	Rotating Lidar Instrument Experiment (HARLIE)	Airborne Compact Atmospheric Mapper (ACAM)	Cloud Radar System (CRS)
	Air Goddard Lidar Observatory for Winds (Air GLOW)		UAV Cloud Physics Lidar (UAV CP Lidar)
Ground/ Laboratory/ Development	Scanning Raman Lidar (SRL)	Stratospheric Ozone Lidar Trailer Experiment (STROZ LITE)	Micro-Pulse Lidar (MPL)
	Goddard Lidar Observatory for Winds (GLOW)	Aerosol and Temperature Lidar (AT Lidar)	Compact Visible Infrared Radiometer (COVIR)
	Lightweight Rain Radiometer-X band (LRR-X)	Brewer UV Spectrometer	Surface-Sensing Measurements for Atmospheric Radiative Transfer (SMART)—Chemical, Optical, and Microphysical Measurements of <i>In situ</i> Troposphere (COMMIT)
		Kiritimati Island Lidar Trailer (KILT)	
		Lagrange-2 Solar Viewing Interferometer Prototype (L2-SVIP) Instrument Incubator Program (IIP)	
		GeoSpec (IIP)	
		CO ₂ Lidar	

4.2 Field Campaigns

Field campaigns use the resources of NASA, other agencies, and other countries to carry out scientific experiments, to validate satellite instruments, or to conduct environmental impact assessments from bases throughout the world. Research aircraft, such as the NASA ER-2, DC-8, and WB-57F serve as platforms from which remote sensing and *in situ* observations are made. Ground-based systems are also used for soundings, remote sensing, and other radiometric measurements. In 2005, Laboratory personnel supported many such activities as scientific investigators, or as mission participants, in the planning and coordination phases.

Aura Validation Experiment (AVE)

AVE is a measurement campaign designed to acquire correlative data needed for the validation of the Aura AVE is a measurement campaign designed to acquire correlative data needed for the validation of the Aura satellite instruments. Aura was launched in July 2004 with four instruments: OMI, TES, MLS, and the High Resolution Dynamics Limb Sounder (HIRDLS). Aura has three science objectives: 1) analyze the recovery of the ozone layer, 2) assess air quality problems, and 3) determine how the Earth's climate is changing.

There have been three AVE missions flown since the Aura launch. The first AVE campaign was flown from NASA's Johnson Space Center (JSC) Ellington Field in October–November 2004 on the high altitude NASA WB-57F aircraft. The second AVE (the Polar Aura Validation Experiment, PAVE) campaign was flown from Portsmouth, New Hampshire, in January 2005 on the long range NASA DC-8 aircraft. The third campaign was also flown from Ellington Field in June 2005 on the high altitude NASA WB-57F aircraft. Eight successful science flights were completed over the course of 14 days



Figure 4-1. Instrument locations on the WB-57 for the AVE Houston campaign.

Laboratory members participating in this mission were Paul Newman (613.3, Project Scientist), Scott Janz (613.3, ACAM Principal Investigator [PI]), Kent McCullough (ACAM and Argus Team/SSAI), Rich McPeters

(613.3, Aura/OMI Co-PI), Matt McGill (613.1, CPL PI), Dennis Hlavka (613.1/SSAI, CPL Team), William Hart (613.1/SSAI, CPL Team), and Leslie Lait (613.3/SSAI, Met. Team). For more information, contact Paul A. Newman (Paul.A.Newman@nasa.gov). More information may be found at the Aura Web site: <http://aura.gsfc.nasa.gov/> and the Aura Validation Data Center Web site: <http://avdc.gsfc.nasa.gov/Overview/news.html>.

A fourth AVE is scheduled to be flown from San Jose, Costa Rica in January–February 2006 on the high altitude NASA WB-57F aircraft.

Polar Aura Validation Experiment (PAVE)

The Polar Aura Validation Experiment (PAVE), one of a number of Aura validation experiments, is a NASA international science mission to acquire critical high quality measurements of the polar region in support of the recently launched Aura satellite. PAVE is the third of a series of Aura validation missions designed to provide correlative measurements to help understand the transport of gases and aerosols in the troposphere and their exchange with the lower stratosphere. The PAVE experiment was completed successfully from Pease Tradeport, New Hampshire, in January 2005. The experiment utilized the NASA DC-8, based at Dryden Flight Research Center (DFRC). Included in these flights was AROTAL, which made measurements of O₃, temperature, and aerosol profiles. The AROTAL team on this mission consisted of Tom McGee (613.3, PI), Walter Hoegy (613, Emeritus), Don Silbert (613.3), Grant Sumnicht (613.3/Science Systems and Application, Inc. [SSAI]), and Larry Twigg (613.3/SSAI). The project scientists are Mark Schoeberl (NASA Goddard Space Flight Center [GSFC]) and Eric Jensen (NASA Ames Research Center [ARC]). For more information contact Tom McGee (Thomas.J.McGee@nasa.gov) or Mark Schoeberl (Mark.R.Schoeberl@nasa.gov). More information may be found at the PAVE Web site: <http://cloud1.arc.nasa.gov/ave-polar/>.

CPL Activities

During 2004, the CPL was modified to operate on the NASA WB-57F aircraft. Historically, the CPL operated only on the ER-2 aircraft. Future missions, however, will require use of the WB-57F, so it became imperative to adapt CPL to that aircraft. Mechanical, thermal, and data system modifications were required for operation on the WB-57F. After modifications were made, the CPL participated in the first AVE conducted from Ellington Field in Houston, Texas from October 18 to November 12, 2004. The purpose of this experiment was to validate the instruments onboard the Aura satellite. A total of nine satellite underflights was performed under a variety of atmospheric conditions.

In June 2005, the CPL participated in the second AVE, also conducted from Ellington Field. The NASA WB-57F completed eight successful science flights over the course of 14 days.

For more information on the CPL instrument, or for access to CPL data, visit <http://cpl.gsfc.nasa.gov/>, or contact Matthew McGill (matthew.j.mcgill@nasa.gov).

Airborne Compact Atmospheric Mapper (ACAM)

A new aircraft based measurement program was started in 2005. ACAM was test flown onboard the NASA WB57F during AVE in June of 2005 flying out of Houston, Texas. This new system, developed in the RCDF, combines high resolution photographic imagery of both nadir and forward looking cloud conditions with nadir UV and VIS spectrographic measurements in order to map trace gas concentrations of nitrogen dioxide, ozone, and aerosols. These measurements will be used to validate similar measurements from the Ozone Monitoring Instrument (OMI) onboard Aura. The test flights were successful and led to instrument improvements that will be implemented for the Costa Rica AVE (CR-AVE) mission in February of 2006.

For more information contact Scott Janz (Scott.Janz@nasa.gov) or Paul Newman (Paul.A.Newman@nasa.gov), or visit the Web site at http://code916.gsfc.nasa.gov/Public/Ground_based/acam/acam/html.

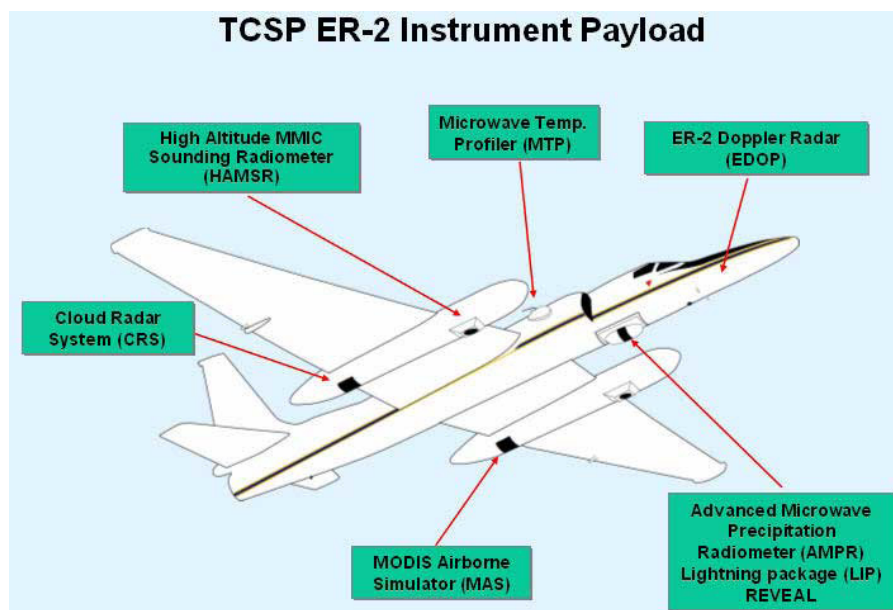
Tropical Cloud Systems and Processes (TCSP)

The Tropical Cloud Systems and Processes (TCSP) mission is an Earth science field research investigation sponsored by NASA's Science Mission Directorate. The field phase was conducted during the period July 1–27, 2005 out of the Juan Santa Maria Airfield in San Jose, Costa Rica. The TCSP field experiment flew 12 NASA ER-2 science flights, including missions to Hurricanes Dennis and Emily, Tropical Storm Gert, and an eastern Pacific mesoscale complex that may possibly have further developed into Tropical Storm Eugene. The P-3 aircraft from the NOAA Hurricane Research Division (HRD) flew 18 coordinated missions with the NASA research aircraft to investigate developing tropical disturbances. Additionally, the aerosonde Unmanned Aerial Vehicle (UAV) flew eight surveillance missions and the *Instituto Meteorologico Nacional* (IMN) of Costa Rica launched RS-92 balloon sondes daily to gather humidity measurements and provide validation of the water vapor measurements.

TCSP is focused on the study of the dynamics and thermodynamics of precipitating cloud systems and tropical cyclones using NASA-funded aircraft and surface remote sensing instrumentation. Targeted data sets were collected using the NASA ER-2 research aircraft, in synergy with other surface and airborne remote sensing observations provided by NASA and other agencies. These observations will be used to answer key questions pertaining to the origins and life cycle of weather disturbances in the tropics. Analyses of data sets will address a wide variety of atmospheric space and time scales, ranging from the convective through the synoptic. Investigations will also be conducted to improve upon numerical modeling studies of tropical cyclogenesis, including wave-to-depression transition in the western Caribbean, Gulf of Mexico, and eastern Pacific Ocean.

TCSP research addresses the following topical areas: 1) tropical cyclone structure, genesis, intensity change, moisture fields and rainfall; 2) satellite and aircraft remote sensor data assimilation and validation studies pertaining to development of tropical cyclones; and 3) the role of upper tropospheric/lower stratospheric processes governing tropical cyclone outflow, the response of wave disturbances to deep convection, and the evolution of the upper level warm core.

The TCSP experiment builds upon the success of the previous Convection and Moisture Experiment (CAMEX) missions. For further information contact Gerald Heymsfield (Gerald.M.Heymsfield@nasa.gov) or visit the TCSP Web site at <http://camex.msfc.nasa.gov>.



4.3 Data Sets

In the previous discussion, we examined the array of instruments and some of the field campaigns that produce the atmospheric data used in our research. The raw and processed data from these instruments and campaigns is used directly in scientific studies. Some of this data, plus data from additional sources, is arranged into data sets useful for studying various atmospheric phenomena. The major data sets are described in the following paragraphs.

50-Year Chemical Transport Model (CTM) Output

A 50-year simulation of stratospheric constituent evolution has been completed using the Code 613.3 three-dimensional chemistry and transport model. Boundary conditions were specified for chlorofluorocarbons, methane, and N₂O appropriate for the period 1973–2023. Sulfate aerosols were also specified, and represent the eruptions of El Chichón and Mt. Pinatubo. Simulations with constant chlorine (1979 source gases) and low chlorine (1970 levels) and without the volcanic aerosols have also been completed to help distinguish chemical effects from effects of both interannual variability and a trend in the residual circulation in the input meteorological fields. The model output from all simulations is available on the Code 613.3 science system; software to read the output is also available. Although the CTM itself is run at $2^\circ \times 2.5^\circ$ latitude/longitude horizontal resolution; the output is stored at $4^\circ \times 5^\circ$ latitude/longitude. Higher resolution files are available from UniTree, the Code 606.2 archive. The model output stored on the science system is for six days each month (1, 5, 10, 15, 20, 25); daily fields are saved on UniTree. Details about this and other CTM simulations are available from the Code 613.3 Web site at <http://code916.gsfc.nasa.gov/Public/Modelling/3D/exp.html>. Questions or comments should be addressed to Anne Douglass (Anne.R.Douglass@nasa.gov).

Near-UV Aerosol Products from TOMS and OMI

The near-UV technique of aerosol characterization differs from conventional visible and near-IR methods in that the UV measurements can separate UV-absorbing aerosol (such as desert dust, smoke from biomass burning, and volcanic ash) from nonabsorbing aerosol (such as sulfates, sea salt, and ground-level fog). In addition, the UV technique can detect aerosol over water and land surfaces, including deserts, where traditional visible (VIS) and near-infrared (IR) methods do not work. TOMS aerosol data are currently available in the form of a contrast index and as near-ultraviolet (UV) extinction optical depth. The science value of the TOMS aerosol information has been enhanced by the application of an inversion procedure to the TOMS measured radiances to derive the near-UV extinction optical depth and single-scattering albedo of aerosol. Satellite-derived single scattering albedo from TOMS observations for biomass burning episodes was evaluated by comparison to the Aerosol Robotic Network (AERONET) ground based retrievals. The evaluation indicates that the TOMS and AERONET single-scattering albedo products are in agreement within 0.03 in most cases.

The record of Aerosol Index and near-UV aerosol properties will be extended into the future making use of observations by the Ozone Monitoring Instrument (OMI) on the Aura spacecraft, launched on July 2004. The figure below shows a 4-day sequence of a Saharan dust outbreak in March 2005 as seen by OMI.

For more information contact Omar Torres (torres@tparty.gsfc.nasa.gov).

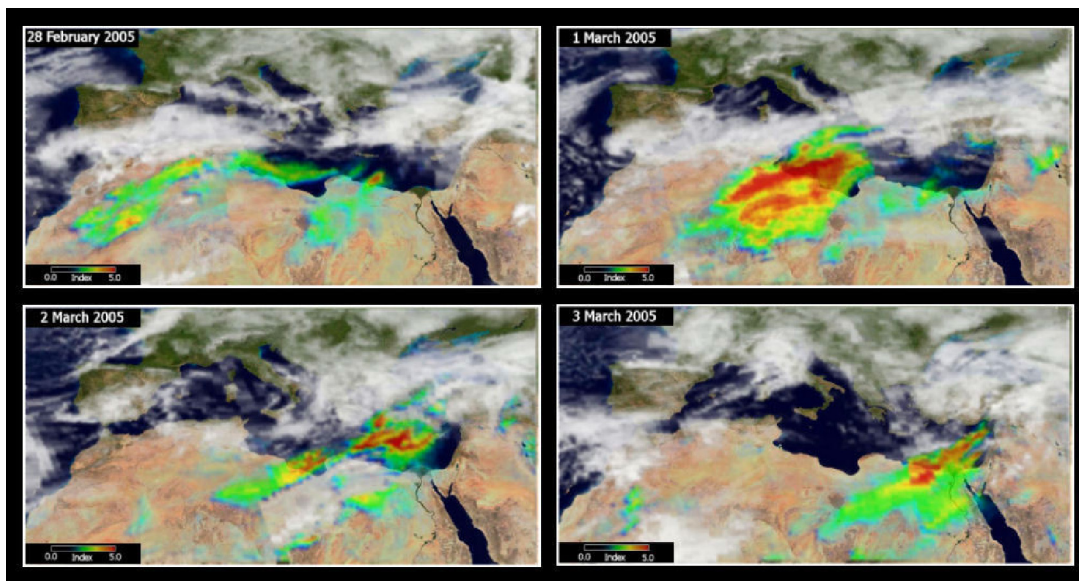


Figure 4-2. Saharan dust aerosols as seen by the Aura-OMI sensor Aerosol Index. The aerosol detection capability in the presence of clouds is a unique advantage of the OMI and TOMS observations.

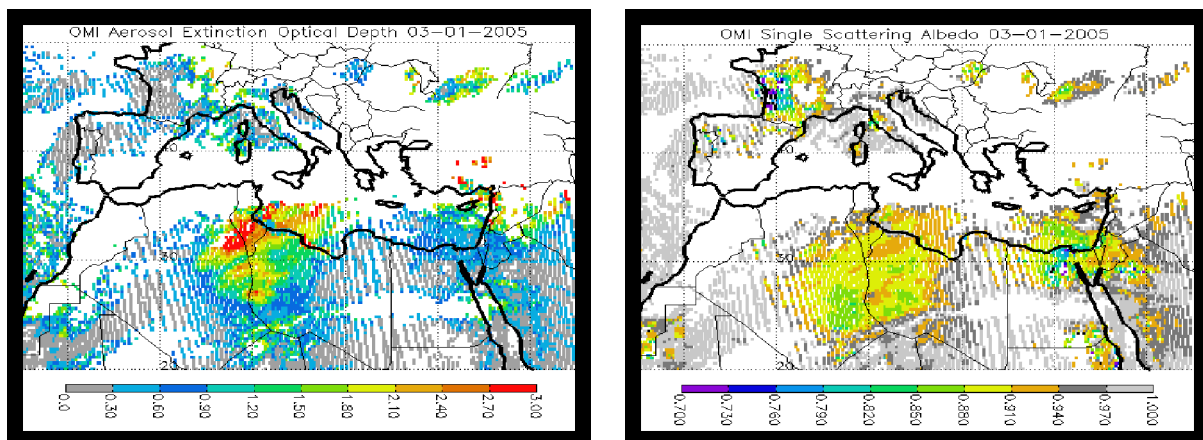


Figure 4-3. OMI retrievals of aerosol extinction optical; depth (left), single scattering albedo (right), during a Saharan dust outbreak on March 1, 2005.

Global Precipitation

An up-to-date, long, continuous record of global precipitation is vital to a wide variety of scientific activities. These include initializing and validating numerical weather prediction and climate models, providing input for hydrological and water cycle studies, supporting agricultural productivity studies, and diagnosing climatic fluctuations and trends on regional and global scales.

At the international level, the Global Energy and Water Cycle Experiment (GEWEX) component of the World Climate Research Programme (WCRP) has established the Global Precipitation Climatology Project (GPCP) to develop such global data sets. Scientists working in the Laboratory are leading the GPCP effort to merge data from both low-Earth orbit satellites and geosynchronous satellites, and ground-based rain gauges, to produce research-quality estimates of global precipitation.

The GPCP data set provides global, monthly precipitation estimates for the period January 1979 to the present. Updates are being produced on a quarterly basis. The release includes input fields, combination products, and error estimates for the rainfall estimates. The data set is archived at NOAA's National Climatic Data Center in Asheville, North Carolina and at the Goddard Distributed Active Archive Center (DAAC). Evaluation is ongoing for this long-term data set in the context of climatology, El Niño Southern Oscillation (ENSO)-related variations, and regional and global trends. The eight-year TRMM data set is being used in the assessment of the longer GPCP data set. A daily, globally complete analysis of precipitation is also being produced by Laboratory scientists for GPCP for the period 1997 to the present and is available from the archives.

An even finer time resolution, a TRMM-based quasi-global, 3 h resolution rainfall analysis, the TRMM Multi-satellite Precipitation Analysis (TMPA) is available from the Goddard DAAC for the period of January 1998 to the present. This product uses TRMM data to calibrate or adjust rainfall estimates from other satellite data and combines these estimates into rainfall maps at a frequency of every 3 h. A real-time version of this analysis is available through the TRMM Web site. For more information, contact Robert Adler (Robert.F.Adler@nasa.gov).

Merged TOMS/SBUV Data Set

We have recently updated our merged satellite total ozone data set through late 2005. We have transferred the calibration from the original six satellite instruments to the current instrument NOAA 16 SBUV/2. We also have a merged profile data set from the SBUV instruments. The data, and information about how they were constructed, can be found at http://code916.gsfc.nasa.gov/Data_services/merged. It is expected that these data will be useful for trend analyses, for ozone assessments, and for scientific studies in general. During 2006, we will incorporate the data from the OMI instrument on Aura. For further information, contact Richard Stolarski (Richard.S.Stolarski@nasa.gov) or Stacey Frith (smh@code916.gsfc.nasa.gov). For further information, contact Richard Stolarski (Richard.S.Stolarski@nasa.gov) or Stacey Frith (smh@code916.gsfc.nasa.gov).

Moderate Resolution Imaging Spectroradiometer (MODIS)

Operational MODIS data includes both level-2 and level-3 products. There are six categories of level-2 (pixel-level or swath data) MODIS Atmosphere products collected from two platforms: Terra and Aqua. There are three level-3 (global gridded) MODIS Atmosphere Products produced from each platform. Each of the level-3 products contains statistics generated from the first four level-2 products noted below.

The level-2 product files are grouped by Aerosol, Water Vapor, Cloud, Atmospheric Profile, and Cloud Mask geophysical retrievals. In addition, the Joint Atmosphere Product contains a spatial sample of the more popular atmospheric retrievals. Level-3 MODIS Atmosphere products provide statistics on a $1^\circ \times 1^\circ$ global grid and are produced for daily, eight-day, and monthly time periods.

Level-2 Products

The Aerosol Product provides aerosol optical thickness over the oceans globally and over a portion of the continents. Further, information regarding the aerosol size distribution is derived over the oceans, while the aerosol type is derived over continents. Level-2 aerosol retrievals are at the spatial resolution of a 10×10 , 1 km (at nadir) pixel array.

The Precipitable Water Product consists of two-column water vapor retrievals. During the daytime, a near-infrared algorithm is applied over clear land areas, ocean sun glint areas, and above clouds over both land and ocean. An infrared algorithm used in deriving atmospheric profiles is also applied both day and night.

The Cloud Product combines infrared and visible techniques to determine both physical and radiative cloud properties. Cloud optical thickness, effective particle radius, and water path are derived at a 1 km resolution using MODIS visible through mid-wave infrared channel observations. Cloud-top temperature, pressure, and effective emissivity are produced by infrared retrieval methods, both day and night, at a 5×5 , 1 km pixel resolution. Cloud thermodynamic phase is derived from a combination of techniques and spectral bands. Finally, the MODIS Cloud Product includes an estimate of cirrus reflectance in the visible at a 1 km pixel resolution; these retrievals are useful for removing cirrus scattering effects from the land-surface reflectance product.

The Atmospheric Profile Product consists of several parameters: total column ozone, atmospheric stability, temperature and moisture profiles, and atmospheric water vapor. All of these parameters are produced day and night at a 5×5 , 1 km pixel resolution when a 5×5 region is suitably cloud free.

The Cloud Mask Product indicates to what extent a given instrument field of view (FOV) of the Earth's surface is unobstructed by clouds. The cloud mask also provides additional information about the FOV, including the presence of cirrus clouds, ice/snow, and sun glint contamination.

The Joint Atmosphere Product contains a subset of key parameters gleaned from the complete set of operational level-2 products: Aerosol, Water Vapor, Cloud, Atmospheric Profile, and Cloud Mask. The Joint Atmosphere product was designed to be small enough to minimize data transfer and storage requirements, yet robust enough to be useful to a significant number of MODIS data users. Scientific data sets (SDSs) contained within the Joint Atmosphere Product cover a full set of high-interest parameters produced by the MODIS Atmosphere Group, and are stored at 5 km and 10 km (at nadir) spatial resolutions.

Level-3 Products

The Level-3 MODIS *Atmosphere Daily Global Product* contains roughly 600 statistical data sets, which are derived from approximately 80 scientific parameters from four Level-2 MODIS Atmosphere Products: Aerosol, Water Vapor, Cloud, and Atmospheric Profile. Statistics are sorted into $1^\circ \times 1^\circ$ cells on an equal-angle grid that spans 24 hours (0000 to 2400 UTC). A range of statistical quantities is computed, depending on the parameter being considered. In addition to simple statistics, the level-3 files include a variety of one- and two-dimensional histograms. Similarly, the level-3 *Eight-Day* and *Monthly Global Product* contain roughly 800 statistical data sets that are derived from the level-3 *Daily* and *Eight-Day* products, respectively.

For further information, contact Steven Platnick (Steven.Platnick@nasa.gov) or visit the MODIS Web site at <http://modis-atmos.gsfc.nasa.gov/>. Discussion of the MODIS data processing is contained in Section 5 of this report.

MPLNET Data Sets

The Micro-Pulse Lidar Network (MPLNET) is composed of ground-based lidar systems co-located with sun-sky photometer sites in the NASA AERONET. The MPLNET project uses the MPL system, a compact and eye-safe lidar capable of determining the range of aerosols and clouds continuously in an autonomous fashion. The unique capability of this lidar to operate unattended in remote areas makes it an ideal instrument to use for a network. The primary purpose of MPLNET is to acquire long-term observations of aerosol and cloud vertical structure at key sites around the world. These types of observations are required for several NASA satellite validation programs, and are also a high priority in the Third Assessment Report of the Intergovernmental Panel on Climate Change (IPCC). The combined lidar and sun photometer measurements are able to produce quantitative aerosol and cloud products such as optical depth, sky radiance, vertical structure, and extinction profiles.

MPLNET results have contributed to studies of dust, biomass, marine, and continental aerosol properties, the effects of soot on cloud formation, aerosol transport processes, and polar clouds and snow. MPLNET sites served

as ground calibration/validation for NASA's first satellite lidar, the Geoscience Laser Altimeter System (GLAS), and will also provide validation for the next satellite lidar, the Cloud-Aerosol Lidar and Infrared Pathfinder Satellite Observations (CALIPSO). MPLNET data has also been used to validate results from passive NASA satellite sensors such as MODIS, the Multi-Angle Imaging Spectroradiometer (MISR), and TOMS.

The MPLNET project underwent a major expansion in 2005. There are currently 10 active sites in the network: three in the U.S., three in Asia, two in Antarctica, one in the Arctic, and one off the west coast of Africa. Data from several of the sites are already publicly available on our Web site, and the remaining sites will soon be public after the calibrations are completed (data is being acquired offline in the interim). Older data sets from an additional 14 sites remain available as well. Planning is underway for future sites in 2006, including additional sites in the U.S., Asia, the west coast of Africa, and new sites in the Caribbean, South America, and the Middle East.

Further information on the MPLNET project, and access to data, may be obtained online at <http://mplnet.gsfc.nasa.gov>. For questions on the MPLNET project, contact Judd Welton (Judd.Welton@nasa.gov).

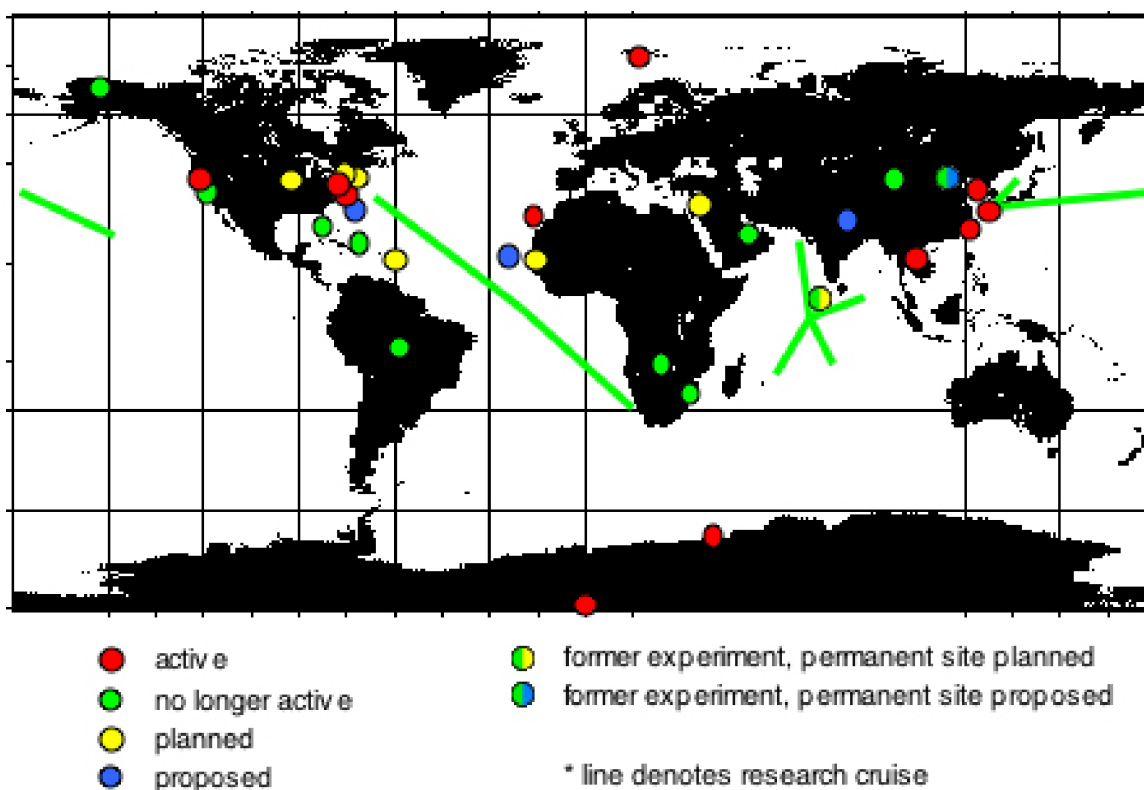


Figure 4.4. MPLNET sites

Skyrad Ground-Based Observations

Skyrad, a ground-based measurement program to observe the zenith sky, continues to investigate radiative transfer properties of the atmosphere in the near-UV and visible (300–500 nm). The purpose of these observations is to test the accuracy of the Laboratory's radiative transfer models, to improve ozone algorithms (for both ground and space), and to validate orbiting satellite instruments, which also operate in this wavelength range. There are now several U.S. and international instruments in orbit (Aura, TOMS, and EnviSat) operating in this wavelength range. The observations are taken from the Laboratory's RCDF, which houses several ground-based instruments, notably the Shuttle Solar Backscatter Ultraviolet (SSBUV) and a double monochromator Brewer

instrument. This location is ideally suited for these studies because several instruments measuring aerosols (AERONET and sun photometers) are located near the RCDF.

Nearly three years of zenith sky data have been taken over a range of sky conditions using SSBUV. In addition, an accurate set of tables of expected zenith sky radiances was calculated for conditions over Goddard, including a range of aerosol characteristics and ozone amounts. Comparisons of observations and models resulted in differences of less than 3%. The zenith data are also being used to derive ozone column amounts and aerosol characteristics in the ultraviolet at high solar zenith angles. Accurate ground-based measurements of ozone under these conditions are desperately needed for validation of satellite data. Errors in satellite observation are largest at high solar zenith angles, a critical region for observing ozone trends. The GSFC Brewer monochromator has been modified and further calibrated to measure, in addition to ozone, nitrogen dioxide, sulfur dioxide, and the absorbing properties of aerosols, which is a new application for this instrument. These measurements are being proposed for local air-quality observations and for validating the OMI flying on Aura, as well as similar instruments flying on European satellites. For more information, contact Scott Janz (Scott.Janz@nasa.gov) or Jay Herman (Jay.R.Herman@nasa.gov).

TIROS Operational Vertical Sounder (TOVS) Pathfinder

The Pathfinder Projects are joint NOAA–NASA efforts to produce multiyear climate data sets using measurements from instruments on operational satellites. One such satellite-based instrument suite is TOVS. TOVS is composed of three atmospheric sounding instruments: the High Resolution Infrared Sounder-2 (HIRS-2), the Microwave Sounding Unit (MSU), and the Spectral Sensor Unit (SSU). These instruments have flown on the NOAA Operational Polar Orbiting Satellite since 1979. We have reprocessed TOVS data from 1979 until April 2005, when NOAA 14 stopped transmitting data. We used an algorithm developed in the Laboratory to infer temperature and other surface and atmospheric parameters from TOVS observations.

The TOVS Pathfinder Path A data set covers the period 1979–2004 and consists of global fields of surface skin and atmospheric temperatures, atmospheric water vapor, cloud amount, cloud height, Outgoing Longwave Radiation (OLR), clear sky OLR, and precipitation estimates. The data set includes data from TIROS N, and NOAA 6, 7, 8, 9, 10, 11, 12, and 14. Equivalent future data sets will be produced from Atmospheric Infrared Sounder (AIRS) data on EOS Aqua. We have demonstrated with the 25-year TOVS Pathfinder Path A data set that TOVS data can be used to study interannual variability, trends of surface and atmospheric temperatures, humidity, cloudiness, OLR, and precipitation. The TOVS precipitation data are being incorporated in the monthly and daily GPCP precipitation data sets.

We have also developed the methodology used by the AIRS science team to generate products from AIRS for weather and climate studies, and continue to improve the AIRS science team retrieval algorithm. A new algorithm, Version 4.0, was recently delivered to NASA's Jet Propulsion Laboratory (JPL.) The Goddard DAAC has been producing AIRS level-2 soundings since September 2002 using an early version of the AIRS science team retrieval algorithm. The DAAC began producing improved AIRS level-2 soundings starting in April 2005 based on the Version 4.0 AIRS Science Team retrieval algorithm. All products obtained in the TOVS Pathfinder data set will also be produced from AIRS, including precipitation estimates. In joint work with Robert Atlas, AIRS temperature profiles derived using this improved retrieval algorithm have been assimilated into the Laboratory forecast analysis system and have shown a significant improvement in weather prediction skill. For more information, contact Joel Susskind (Joel.Susskind-1@nasa.gov).

TOMS and OMI Data Sets

Since the Atmospheric Chemistry and Dynamics Branch first formed, it has been tasked with making periodic ozone assessments. Through the years the Branch has led the science community in conducting ozone research

by making measurements, analyzing data, and modeling the chemistry and transport of trace gases that control the behavior of ozone. This work has resulted in a number of ozone and related data sets based on the TOMS instrument. The first TOMS instrument flew onboard the Nimbus-7 spacecraft and produced data for the period from November 1978 through May 6, 1993 when the instrument failed. Data are also available from the Meteor-3 TOMS instrument (August 1991–December 1994) and from the TOMS flying on the Earth Probe (EP-TOMS) spacecraft (July 1996–present).

TOMS data are given as daily files of ozone, reflectivity, aerosol index, and erythemal UV flux at the ground. A new Version 8 algorithm was released in 2004, which addresses errors associated with extreme viewing conditions. These data sets are described on the Atmospheric Chemistry and Dynamics Branch Web site, which is linked to the Laboratory Web site, <http://atmospheres.gsfc.nasa.gov/>. Click on the “Code 613.3” Branch site, and then click on “Data Services.” The TOMS spacecraft and data sets are then found by clicking on “TOMS Total Ozone data.” Alternatively, TOMS data can be accessed directly from <http://toms.gsfc.nasa.gov>.

Very similar data are being produced by the OMI instrument on the recently launched Aura spacecraft and are also available from the TOMS Web site <http://toms.gsfc.nasa.gov>. Because of calibration problems with the aging EP-TOMS instrument, OMI data should be used in preference to TOMS data beginning in 2005.

Tropospheric O₃ Studies

In 2005, new Aura satellite ozone measurements from the OMI and Microwave Limb Sounder (MLS) were used to develop global maps of tropospheric ozone. Day-to-day tropospheric ozone maps from OMI/MLS were processed for more than one year beginning in August 2004. OMI/MLS tropospheric ozone data were validated from ground-based and other satellite-based measurements. Evaluation of OMI/MLS tropospheric ozone shows evidence of a one-to-two month Madden-Julian Oscillation (MJO) in the tropical Pacific. The data also indicate enhancements in tropospheric ozone over Indonesia during November 2004, which coincided with a weak tropical El Niño event. Features in summer months include an accumulation of tropospheric ozone over the broad Mediterranean region as suggested in past modeling studies. General features (e.g., seasonal cycles, spatial patterns) in tropospheric ozone from OMI/MLS compared well with both NCAR’s Model for Ozone and Related Chemical Tracers (MOZART-2) and Goddard’s GMI CTM modeled tropospheric ozone. Daily maps of tropospheric ozone from OMI/MLS have been evaluated and further tested for the application of tracking global pollution events. The new tropospheric ozone maps from OMI/MLS have been shown at many national and international science meetings by both modelers and nonmodelers within Code 613.3 (Atmospheric Chemistry and Dynamics Branch). For more information contact Jerry Ziemke (Jerald.R.Ziemke.1@gsfc.nasa.gov).

4.4 Data Analysis

A considerable effort by our scientists is spent in analyzing the data from a vast array of instruments and field campaigns. This section details some of the major activities in this endeavor.

Aerosol and Water Cycle Dynamics

Aerosol can influence the regional, and possibly the global, water cycle by changing the surface energy balance, modifying cloud microphysics, and altering cloud and rainfall patterns. On the other hand, condensation heating from rainfall, and radiative heating from clouds and water vapor associated with fluctuations of the water cycle, drive circulation, which determines the residence time and transport of aerosols, and their interaction with the water cycle. Understanding the mechanisms and dynamics of aerosol-clouds-precipitation, and eventually implementing realistic aerosol-cloud microphysics in climate models are clearly important pathways to improve the reliability of predictions by climate and Earth system models.

Laboratory scientists are involved in analyses of the interrelationships among satellite-derived quantities such as cloud optical properties, effective cloud radii, aerosol optical thickness (MODIS, TOMS, CloudSat, and CALIPSO) rainfall, water vapor, cloud liquid water (TRMM, Advanced Microwave Sounding Radiometer [AMS]), in conjunction with large scale circulation, moisture convergence (European Centre for Medium-Range Weather Forecasts [ECMWF] and National Center for Environmental Prediction [NCEP] re-analyses) in different climatic regions of the world, including the semi-arid regions of southwest U.S., the Middle East, northern Africa, and central and western Asia. Observations are being coordinated with modeling studies, using global and regional climate models, as well as cloud resolving models, coupled to land surface and vegetation models, and ocean models. A major goal of this research is to develop a fully interactive climate-aerosol climate system model, including data assimilation, so that atmospheric water cycle dynamics can be studied in a unified modeling and observational framework. Currently, the use of multimodel framework (MMF), including the embedding of cloud resolving models in global general circulation models, is being pursued. This research also calls for the organization and coordination of field campaigns for aerosol and water cycle measurements in conjunction with GEWEX, Climate Variability and Predictability Programme (CLIVAR), and other WCRP international programs on aerosols and water cycle studies. For more information, contact William Lau (William.K.Lau@nasa.gov), Mian Chin (Mian.Chin@nasa.gov), Si-Chee Tsay (Si-Chee.Tsay-1@climate.gsfc.nasa.gov), or W.K. Tao (Wei-Kuo.Tao-1@nasa.gov).

Atmospheric Hydrologic Processes and Climate

One of the main thrusts in climate research in the Laboratory is to identify natural variability on seasonal, interannual, and interdecadal time scales, and to isolate the natural variability from the human-made global-change signal. Climate diagnostic studies use a combination of remote sensing data, historical climate data, model output, and assimilated data. Diagnostic studies are combined with modeling studies to unravel physical processes underpinning climate variability and predictability. The key areas of research include ENSO, monsoon variability, intraseasonal oscillation, air–sea interaction, and water vapor and cloud feedback processes. More recently, the possible impact of anthropogenic aerosol on regional and global atmospheric water cycles is also included. A full array of standard and advanced analytical techniques, including wavelets transform, multivariate empirical orthogonal functions, singular value decomposition, canonical correlation analysis, nonlinear system analysis, and satellite orbit-related sampling calculations are used. Maximizing the use of satellite data for better interpretation, sampling, modeling, and eventually prediction of geophysical and hydroclimate systems is a top priority of research in the Laboratory.

Satellite-derived data sets for key hydroclimate variables such as rainfall, water vapor, clouds, surface wind, sea surface temperature, sea level heights, and land surface characteristics are obtained from a number of different projects: MODIS, AMSR, TRMM, the Quick Scatterometer Satellite (QuikSCAT) and Topography Experiment (TOPEX)/Poseidon, the Earth Radiation Budget Experiment (ERBE), Clouds and the Earth's Radiant Energy System (CERES), the International Satellite Cloud Climatology Project (ISCCP), Advanced Very High Resolution Radiometer (AVHRR), TOMS, Special Sensor Microwave Imager (SSM/I), MSU, and TOVS Pathfinder. Diagnostic and modeling studies of diurnal and seasonal cycles of various geophysical parameters are being conducted using satellite data to validate climate model output, and to improve physical parameterization in models. For more information, contact William Lau (William.K.Lau@nasa.gov), Tom Bell (Thomas.L.Bell@nasa.gov), or Yogesh Sud (Yogesh.C.Sud@nasa.gov).

Atmospheric Ozone Research

The Clean Air Act Amendment of 1977 assigned NASA the major responsibility for studying the ozone layer. Data from many ground-based, aircraft, and satellite missions are combined with meteorological data to understand the factors that influence the production and loss of atmospheric ozone. Analysis is conducted over

different temporal and spatial scales, ranging from studies of transient filamentary structures that play a key role in mixing the chemical constituents of the atmosphere to investigations of global-scale features that evolve over decades.

The principal goal of these studies is to understand the complex coupling between natural phenomena, such as volcanic eruptions and atmospheric motions, with human-made pollutants, such as those generated by agricultural and industrial activities. These nonlinear couplings have been shown to be responsible for the development of the well-known Antarctic ozone hole.

An emerging area of research is to understand the transport of chemically active trace gases across the tropopause boundary, both into the stratosphere from the troposphere, and out of the stratosphere to the troposphere. It has been suggested that changes in atmospheric circulation caused by greenhouse warming may affect this transport and, thus, delay the anticipated recovery of the ozone layer in response to phase-out of CFCs. For more information, contact Paul A. Newman (Paul.A.Newman@nasa.gov).

First Measurements of Trace Gases (NO_2 , SO_2 , HCHO , O_3) Amounts Using a Brewer Double Monochromator

O_3 , NO_2 , HCHO , and SO_2 column amounts were measured by using a modified double Brewer spectrometer in direct-sun mode. A new “bootstrap” solar irradiance method of solar calibration has enabled the Brewer spectrometer to detect NO_2 , HCHO , and SO_2 with a sensitivity of approximately 0.4 DU. The method for obtaining the column amounts uses a modified differential Optical Absorption Spectroscopy (DOAS) (spectral fitting) technique having the advantage that measured direct sun slant-column amounts can be accurately converted into vertical column amounts without needing to know the height distribution or making the unlikely assumption of horizontal homogeneity, especially in urban areas. The method described in this study can be applied to the worldwide Brewer network to obtain global distributions of pollution related trace gas amounts. Comparisons with Scanning Imaging Absorption Spectrometer for Atmospheric Chartography (SCIAMACHY) NO_2 data show good agreement. The results from this investigation have now been accepted for publication. For more information, contact Jay Herman (Jay.R.Herman@nasa.gov).

First Simultaneous UV and Visible Wavelength Measurements of Aerosol Scattering and Absorption Properties

Very little is known about aerosol absorption in UV compared to the visible spectral region. Without such information, it is impossible to quantify the causes of the observed discrepancy between modeled and measured UV irradiances and photolysis rates. We have performed an aerosol UV absorption closure experiment using a UV-shadowband radiometer and a well-calibrated Cimel Sun–sky run side-by-side continuously for 17 months at the NASA GSFC site in Greenbelt, Maryland. The new combination of the two instruments has enabled the first determination of consistent aerosol scattering and absorption properties in both the visible and UV wavelength regions. Recently, we have extended these measurements by modifying the design of the shadowband instrument to include a new 440 nm channel that overlaps the Cimel sun photometer’s shortest wavelength almucantar channel. The change should bridge the gap between the two data sets. For more information, contact Jay Herman (Jay.R.Herman@nasa.gov).

Impact of Aerosols on Atmospheric Heating and Rainfall

The impact of smoke aerosols generated from biomass burning activities in Southeast Asia on the total reflected solar and emitted thermal radiation (direct and indirect effects) from clouds, was investigated using satellite data. Narrowband radiance measurements were combined with broadband irradiance measurements to quantify how

smoke aerosols modulate the cloud radiative forcing. Results show that smoke in Southeast Asia is frequently present over large areas of cloud-covered regions during boreal spring. Depending on the loading of the smoke aerosols, the reflected solar (emitted thermal) radiation from clouds was reduced by as much as 100 Wm^{-2} or enhanced by as much 20 Wm^{-2} during spring conditions.

The effect of smoke aerosols produced by agricultural practice from the Indochina peninsula on the precipitation over southern China was carried out using long-term (~20 years) measurements of cloud fraction, precipitation, wind circulation, and aerosols from the combined satellite and model reanalysis data sets. We found that there are statistically significant indirect effects from smoke aerosols on clouds and precipitation in the South East and East Asia regions. Results show that the precipitation increased downstream from the peak aerosol concentrations and decreased in regions of high aerosol loading. This is caused by aerosols absorption of short wave radiation increasing air temperature and stabilizing the atmosphere in the area with high aerosol loading. These patterns are consistently observed during March through early May when more aerosols are produced from biomass burning. Mean southwesterly winds transport aerosols from biomass burning regions over dry Indochina to southern China where the mean climate is wetter in the premonsoon season spring of each year. Based on current measurements we find that the southern China monsoon now starts a couple of weeks earlier than the climatological mean onset date because of precipitation increased by aerosol–cloud interaction. We also found that the increase is not due to a northward shift of tropical cloud systems. These results help us understand the impact of large-scale biomass burning on the fresh water distribution in Southeast Asia and also helps in the prediction of the onset of the tropical monsoon system. For more information, contact Jay Herman (Jay.R.Herman@nasa.gov) or Christina Hsu (Nai.C.Hsu@nasa.gov).

Rain Estimation Techniques from Satellites

Rainfall information is a key element in studying the hydrologic cycle. A number of techniques have been developed to extract rainfall information from current and future spaceborne sensor data, including the TRMM satellite and the AMSR on EOS Aqua (AMSR-E).

The retrieval techniques include the following:

- A physical, multifrequency technique that relates the complete set of microwave brightness temperatures to rainfall rate at the surface. This multifrequency technique also provides information on the vertical structure of hydrometeors and on latent heating through the use of a cloud ensemble model. The approach has recently been extended to combine spaceborne radar data with passive microwave observations for improved estimations.
- An empirical relationship that relates cloud thickness, humidity, and other parameters to rain rates, using TOVS and Aqua–AIRS sounding retrievals.

The satellite-based rainfall information has been used to study the global distribution of atmospheric latent heating, the impact of ENSO on global-scale and regional precipitation patterns, the climatological contribution of tropical cyclone rainfall, and the validation of global models. For more information, contact Robert Adler (Robert.F.Adler@nasa.gov).

Rain Measurement Validation for TRMM

The objective of the TRMM Ground Validation Program (GVP) is to provide reliable, instantaneous area- and time-averaged rainfall data from several representative tropical and subtropical sites worldwide for comparison with TRMM satellite measurements. Rainfall measurements are made at Ground Validation (GV) sites equipped with weather radar, rain gauges, and disdrometers. A range of data products derived from measurements obtained

at GV sites is available via the Goddard DAAC. With these products, the validity of TRMM measurements is being established with accuracies that meet mission requirements. For more information, contact Robert Adler (Robert.F.Adler@nasa.gov).

Unified Onboard Processing and Spectrometry

Increasingly, scientists agree that spectrometers are the wave of the future in passive Earth remote sensing. The difficulty, however, stems from the vast volume of data generated by an imaging spectrometer sampling in the spatial and spectral dimensions. The data volume from an advanced spectrometer could easily require 10 times the present EOS Data Information System (EOSDIS) capacity—something NASA simply cannot afford. A group of scientists and engineers at GSFC, led by Si-Chee Tsay, is funded by the Earth Science Technology Office (ESTO) Advanced Component Technologies (ACT), for a project to unify onboard processing techniques with compact, low-power, low-cost, Earth-viewing spectrometers being developed for eventual space missions. The philosophy is that spectrometry and its onboard processing algorithms must advance in lockstep, and eventually unite in an indistinguishable fashion. We envision a future in which archives of the spectrometer output will not be a monstrous data dump of spectra, but rather the information content of those spectra, undoubtedly a much smaller and more valuable data stream. In the meantime, we must quickly find ways to losslessly compress onboard spectra, using a combination of physics-based removal and proximal differencing, to the maximum extent possible.

A system of hyperspectral imager Quantum Well Infrared Photodetectors (QWIP) has been integrated and flight-tested in a Navy research aircraft for building a testbed. We will perform the final phase of this project by flight testing our QWIP with an onboard simulator in the spring peak-season of biomass burning in a Southeast Asia field deployment. Currently, we are analyzing an effective flat-fielding algorithm, which will be applied to the Field Programmable Processor Array (FPPA), also known as Reconfigurable Data Path Processor (FPPA/RDPP) software simulator. In the meantime, we are implementing a cloud-detection algorithm in the FPPA/RDPP software simulator. The final goal is to demonstrate both flat-fielding and cloud-detection in “Real Time.” We are also exploring lossy compressions for specific applications in Earth sciences. For further information, contact Si-Chee Tsay (Si-Chee.Tsay-1@nasa.gov).

4.5 Modeling

Aerosol radiative forcing is one of the largest uncertainties in assessing global climate change. Aerosol is also a key component determining air quality. To understand the various processes that control aerosol properties and to understand the role of aerosol in atmospheric chemistry and climate, we have developed an atmospheric aerosol model, the Global Ozone Chemistry Aerosol Radiation Transport (GOCART) model. This model uses the meteorological fields produced by Goddard’s Global Modeling and Assimilation Office (GMAO, Code 610.1), and includes major types of aerosol: sulfate, dust, black carbon, organic carbon, and sea salt. Among these, sulfate, and black- and organic carbon originate mainly from human activities—such as fossil fuel combustion and biomass burning—while dust and sea salt are mainly generated by natural processes, for example, uplifting dust from deserts by strong winds.

In 2005, the GOCART model was used as a major tool in the U.S. Climate Change Science Program (CCSP) report on aerosol direct radiative forcing assessment, which has contributed to the most recent report by the Intergovernmental Panel on Climate Change (IPCC). We have also used the model to study intercontinental transport, global air quality, aerosol climate forcing, and aerosol–chemistry–climate interactions. The output of the model is used by many groups worldwide. For more information, contact Mian Chin (Mian.Chin@nasa.gov), or go to the Web site <http://code916.gsfc.nasa.gov/People/Chin/aot.html>.

Chemistry-Climate Modeling

This project brings together the atmospheric chemistry and transport modeling of the Atmospheric Chemistry and Dynamics Branch and the General Circulation Model (GCM) development of the GMAO. The initial goal is to understand the role of climate change in determining the future composition of the atmosphere. We have coupled our stratospheric chemistry and transport into the Goddard Earth Observing System (GEOS) general circulation model and will use this to study the past and future coupling of the stratospheric ozone layer to climate. Our emphasis is on the testing of model processes and model simulations using data from satellites and ground-based measurement platforms.

Co-PIs are Richard Stolarski (Atmospheric Chemistry and Dynamics Branch) and Steven Pawson (GMAO). For further information, contact Richard Stolarski (Richard.S.Stolarski@nasa.gov), Steven Pawson (Steven.Pawson-1@nasa.gov), or Anne Douglass (Anne.R.Douglass@nasa.gov).

Cloud and Mesoscale Modeling

Three different coupled modeling systems were developed and improved over the last year. These models are used in a wide range of studies, including investigations of the dynamic and thermodynamic processes associated with cyclones, hurricanes, winter storms, cold rainbands, tropical and mid-latitude deep convective systems, surface (i.e., ocean and land, and vegetation and soil) effects on atmospheric convection, cloud–chemistry interactions, cloud–aerosol interactions, and stratospheric–tropospheric interaction. Other important applications include long-term integrations of the models that allow for the study of air–sea, cloud–aerosol, cloud–chemistry (transport), and cloud–radiation interactions and their role in cloud–climate feedback mechanisms. Such simulations provide an integrated system-wide assessment of important factors such as surface energy, precipitation efficiency, radiative exchange processes, and diabatic heating and water budgets associated with tropical, subtropical, and mid-latitude weather systems.

In the first modeling system, the NASA Goddard finite volume GCM (fvGCM) is coupled to the Goddard Cumulus Ensemble (GCE) model (a cloud-resolving model). The fvGCM allows for global coverage, and the GCE model allows for explicit simulation of cloud processes and their interactions with radiation and surface processes. This modeling system has been applied and its performance tested for two different climate scenarios, El Niño (1998) and La Niña (1999). The new coupled modeling system produced more realistic propagation and intensity of tropical rainfall systems, intraseasonal oscillations, and diurnal variation of precipitation over land, which are very difficult to forecast using even state-of-the-art GCMs.

The second modeling system couples various NASA Goddard physical packages (i.e., microphysics, radiation, and a land surface model) into the next generation weather forecast model known as the Weather Research and Forecasting (WRF) model. This coupled modeling system allows for better forecasts (or simulations) of convective systems in Oklahoma and typhoons in the west Pacific.

The third modeling system is the improved GCE model system, which has been developed and improved at Goddard over the last two decades. The GCE model has recently been improved in its abilities to simulate the impact of atmospheric aerosol concentration on precipitation processes and the impact of land and ocean surfaces on convective systems in different geographic locations. The improved GCE model has also been coupled with the NASA TRMM microwave radiative transfer model and precipitation radar model to simulate satellite-observed brightness temperatures at different frequencies. This new coupled model system allows us to better understand cloud processes in the tropics, as well as to improve precipitation retrievals from NASA satellites. The scientific output of the modeling activities was again exceptional in 2005 with 10 new papers published or in press and many more submitted. For more information, contact Wei-Kuo Tao (WeiKuo.Tao.1@gsfc.nasa.gov).

Global Modeling Initiative (GMI)

The GMI was initiated under the auspices of the Atmospheric Effects of Aviation Program in 1995. The goal of GMI is to develop and maintain a state-of-the-art modular 3-D chemical transport model (CTM), which can be used for assessment of the impact of various natural and anthropogenic perturbations on atmospheric composition and chemistry, including, but not limited to, the effect of aircraft. The GMI model also serves as a testbed for model improvements. The goals of the GMI effort follow:

- reduce uncertainties in model results and predictions by understanding the processes that contribute most to the variability of model results, and by evaluating model results against existing observations of atmospheric composition;
- understand the coupling between atmospheric composition and climate through coordination with climate models; and
- contribute to the assessment of the anthropogenic perturbations to the Earth system.

The GMI CTM has options for several chemical mechanisms for studying different problems. There are separate tropospheric, stratospheric, and aerosol chemical mechanisms, and recently we have added a combined tropospheric-stratospheric mechanism for investigations of the climatically sensitive upper troposphere/lower stratosphere. We have also added a microphysical aerosol mechanism for the study of aerosol size distributions and their role as cloud condensation nuclei. The chemical mechanisms have been recoded for compliance with the Earth Science Modeling Framework (ESMF). The sensitivity of the aerosol model results to meteorological input was evaluated by GMI team members at the University of Michigan. The GMI tropospheric model participated in an IPCC photochemical intercomparison that investigated model sensitivities to simulation of tropospheric ozone. An important aspect of all GMI studies is the evaluation of the credibility of model results using ground-based, aircraft, and remotely sensed measurements. Comparison to stratospheric observations and to tropospheric observations have been documented for model evaluation. For more information, contact Jose Rodriguez (jrodriguez@code916.gsfc.nasa.gov).

Physical Parameterization in Atmospheric GCM

The development of submodels of physical processes (physical parameterizations) is an integral part of preparing our climate models for addressing the remaining outstanding climate change questions. At this time, the scientific community is deeply divided about the feedback influence of clouds and cloud microphysics in a climate change scenario. Laboratory scientists are actively involved in developing and improving physical parameterizations of the moist processes effecting precipitation microphysics, cloud-radiation, and cloud-aerosol interaction, and in validation against *in situ* data and satellite data. The accuracy of such process interactions is extremely important for eliminating climate-model biases, and simulating realistic climate change, both of which are vital to a better understanding of the global water and energy cycles.

For atmospheric radiation, we are developing efficient, accurate, and modular longwave and shortwave radiation codes with parameterized direct effects of man-made and natural aerosols. The radiation codes allow efficient computation of climate sensitivities to water vapor, cloud microphysics, and optical properties of clouds and aerosols to simulate the direct effects of aerosols. The codes also allow us to compute the global warming potentials of carbon dioxide and various trace gases.

With regard to the cloud physics, almost all of the state-of-the-art models of our times develop large simulation biases that are sometimes larger than the outstanding climate change issues to be assessed by these models; it is primarily due to the biased heating and moistening fields simulated by the model's cloud physics and microphysics. We are evaluating and eliminating such simulation biases using the Microphysics of Clouds with the Relaxed Arakawa-Schubert Scheme (McRAS), an in-house prognostic cloud-scale dynamics and cloud water

substance scheme that includes representation of source and sink terms of cloud-scale condensation, microphysics of precipitation and evaporation, as well as horizontal and vertical advection of cloud water substance. Our cloud scheme incorporates attributes from physically based cloud life cycles, effects of convective updrafts and downdrafts, cloud microphysics within convective towers and anvils, cloud-radiation interactions, and cloud inhomogeneity corrections for radiative transfers based on algorithms developed by the laboratory scientists. The boundary-layer clouds are based on the physics of boundary-layer convection, which parallels the formulations of moist convection. Recently, we included a version of Nenes and Seinfeld aerosol-cloud interaction scheme for water clouds while a parallel scheme for ice and mixed-phase clouds is an active area of research. These will be evaluated against ARM-2004 data on cloud particle number densities of water and ice clouds.

We have been evaluating coupled radiation and the prognostic cloud-water schemes with *in situ* observations from the ARM Cloud and Radiation Test Bed (ARM CART) and Tropical Ocean Global Atmosphere–Coupled Ocean Atmosphere Response Experiment (TOGA COARE) Integrated Program Offices (IOPs), as well as satellite data. Recently, GCM-simulated diurnal cycle of rainfall, that shows significantly different characteristics in different regions of the world, has become an active area of research; TRMM satellite rainfall retrievals also provide the essential validation statistics.

We have been using the Land Information System (LIS) for comparing four different sets of algorithms used to represent the hydrologic, snow-cover, and evapotranspiration processes for different biomes in each model. Moreover, the soil moisture prediction of our own model, called HYdrology and Simple Biosphere (HY-SiB) is extended down to the groundwater table. Two-year long integration with Global Soil Wetness Project (GSWP) forcing data from analysis of observations from 1987 and 1988 revealed several salient characteristics of each land model that would significantly impact climate change studies. All these improvements have been found to better represent the hydrologic cycle in climate simulation studies. Currently, we are performing objective intercomparisons of different parameterization concepts (applied to models and satellite data retrievals) within the GSFC laboratories. After the formation of the Global Modeling and Assimilation Office (GMAO), however, the project is currently with the Hydrospheric and Biospheric Sciences Laboratory and the GMAO. The National Center for Atmospheric Research (NCAR), GFDL, and Goddard Institute for Space Studies (GISS) scientists are our active collaborators. For more information, contact Yogesh Sud (Yogesh.C.Sud@nasa.gov).

Trace Gas Modeling

The Atmospheric Chemistry and Dynamics Branch has developed two- and three-dimensional (2-D and 3-D, respectively) models to understand the behavior of ozone and other atmospheric constituents. We use the 2-D models primarily to understand global scale features that evolve in response to both natural effects, such as variations in solar luminosity in ultraviolet, volcanic emissions, or solar proton events, and human effects; such as changes in chlorofluorocarbons (CFCs), nitrogen oxides, and hydrocarbons. Three-dimensional stratospheric chemistry and transport models simulate the evolution of ozone and trace gases that effect ozone. The constituent transport is calculated using meteorological fields (winds and temperatures) generated by the GMAO or using meteorological fields that are output from a GCM. These calculations are appropriate to simulate variations in ozone and other constituents for time scales ranging from several days or weeks to seasonal, annual, and multi-annual. The model simulations are compared with observations, with the goal of illuminating the complex chemical and dynamical processes that control the ozone layer, thereby improving our predictive capability.

The modeling effort has evolved in the following directions:

- (1) Lagrangian models are used to calculate the chemical evolution of an air parcel along a trajectory. The Lagrangian modeling effort is primarily used to interpret aircraft and satellite chemical observations.

- (2) Two-dimensional noninteractive models have comprehensive chemistry routines, but use specified, parameterized dynamics. They are used in both data analysis and multidecadal chemical assessment studies.
- (3) Two-dimensional interactive models include interactions among photochemical, radiative, and dynamical processes, and are used to study the dynamical and radiative impact of major chemical changes.
- (4) Three-dimensional CTMs have a complete representation of photochemical processes and use input meteorological fields from either the data assimilation system or from a general circulation model for transport.

The constituent fields calculated using winds from a new GCM developed jointly by the GMAO and NCAR exhibit many observed features. We have coupled this GCM with the stratospheric photochemistry from the CTM to produce a fully interactive 3-D model that is appropriate for assessment calculations. We are also using output from this GCM in the current CTM for multi-decadal simulations. The CTM is being improved by implementation of a chemical mechanism suitable for both the upper troposphere and lower stratosphere. This capability is needed for interpretation of data from EOS Aura, which was launched in July 2004.

The Branch uses trace gas data from sensors on the Upper Atmosphere Research Satellite (UARS), on other satellites, from ground-based platforms, from balloons, and from various NASA-sponsored aircraft campaigns to test model processes. The integrated effects of processes such as stratosphere-troposphere exchange, not resolved in 2-D or 3-D models, are critical to the reliability of these models. For more information, contact Anne Douglass (Anne.R.Douglass@nasa.gov).

4.6 Support for NOAA Operational Satellites

In the preceding pages, we examined the Laboratory for Atmosphere's Research and Development work in measurements, data sets, data analysis, and modeling. In addition, Goddard supports NOAA's operational remote sensing requirements. Laboratory project scientists support the NOAA Polar Orbiting Environmental Satellite (POES) and the Geostationary Operational Environmental Satellite (GOES) Project Offices. Project scientists ensure scientific integrity throughout mission definition, design, development, operations, and data analysis phases for each series of NOAA platforms. Laboratory scientists also support the NOAA SBUV/2 ozone measurement program. This program is now operational within the NOAA/National Environmental Satellite Data and Information Service (NESDIS). A series of SBUV/2 instruments fly on POES. Postdoctoral scientists work with the project scientists to support development of new and improved instrumentation and to perform research using NOAA's operational data.

The Laboratory is supporting the formulation phase for the next generation GOES mission, known as GOES-R, which will supply a hundredfold increase in real-time data. Laboratory scientists are involved in specifying the requirements for the GOES-R advanced imager, high-resolution sounding suite, solar imaging suite, and *in situ* sensors. They participate in writing each Request for Proposal (RFP), and serve on each Source Evaluation Board (SEB) for the engineering formulation of these instruments. For more information, contact Dennis Chesters (Dennis.Chesters@nasa.gov).

GOES

GSFC project engineering and scientific personnel support NOAA for GOES. GOES supplies images and soundings for monitoring atmospheric processes, such as moisture, winds, clouds, and surface conditions, in real time. GOES observations are used by climate analysts to study the diurnal variability of clouds and rainfall, and to track the movement of water vapor in the upper troposphere. The GOES satellites also carry an infrared multichannel radiometer, which NOAA uses to make hourly soundings of atmospheric temperature and moisture profiles over the United States to improve numerical forecasts of local weather. The GOES project scientist at

Goddard provides free public access to real-time weather images via the World Wide Web (<http://goes.gsfc.nasa.gov/>). For more information, contact Dennis Chesters (Dennis.Chesters@nasa.gov).

NPOESS

The first step in instrument selection for NPOESS was completed with Laboratory personnel participating on the SEB as technical advisors. Laboratory personnel were involved in evaluating proposals for the Ozone Mapper and Profiler System (OMPS) and the Crosstrack Infrared Sounder (CrIS), which will accompany the Advanced Technology Microwave Sounder (ATMS), and Advanced Microwave Sounding Unit (AMSU)-like crosstrack microwave sounder. Collaboration with the IPO continues through the Sounder Operational Algorithm Team (SOAT) and the Ozone Operational Algorithm Team (OOAT) that will provide advice on operational algorithms and technical support on various aspects of the NPOESS instruments. In addition to providing an advisory role, members of the Laboratory are conducting internal studies to test potential technology and techniques for NPOESS instruments. We have conducted numerous trade studies involving CrIS and ATMS, the advanced infrared and microwave sounders, which will fly on NPP and NPOESS. Simulation studies were conducted to assess the ability of AIRS to determine atmospheric CO₂, CO, and CH₄. These studies indicate that total CO₂ can be obtained to 2 ppm (0.5%) from AIRS under clear conditions, total CH₄ to 1%, and total CO to 15%. This shows that AIRS should be able to produce useful information about atmospheric carbon. For more information, contact Joel Susskind (Joel.Susskind-1@nasa.gov).

CrIS for NPP

CrIS is a high-spectral resolution interferometer infrared sounder with capabilities similar to those of AIRS. AIRS was launched with AMSU-A and the Humidity Sounder for Brazil (HSB) on the EOS Aqua platform on May 4, 2002. Scientific personnel have been involved in developing the AIRS Science Team algorithm to analyze the AIRS/AMSU/HSB data. Current results with AIRS/AMSU/HSB data demonstrate that the temperature sounding goals for AIRS, i.e., root mean squared (RMS) accuracy of 1K in 1 km layers of the troposphere under partial cloud cover, are being met over the ocean. The AIRS soundings will be used in a pseudo-operational mode by NOAA/NESDIS and the NOAA/National Center for Environmental Prediction (NCEP). Simulation studies were conducted for the IPO to compare the performance of AIRS/AMSU/HSB with that expected of CrIS, as a function of instrument noise, together with AMSU/HSB. The simulations will help in assessing the noise requirements for CrIS to meet the NASA sounding requirements for the NPP bridge mission in 2006. Trade studies have also been done for ATMS, which will accompany CrIS on the NPP mission and replace AMSU/HSB. For more information, contact Joel Susskind (Joel.Susskind-1@nasa.gov).

Ozone Mapper Profiler Suite (OMPS)

OMPS will become the next U.S. operational ozone sounder to fly on NPOESS. The instrument suite has heritage from TOMS and SBUV for total ozone mapping and ozone profiling. The need for high performance profiles providing better vertical resolution in the lower stratosphere resulted in the addition of a limb scattering profiler to the suite. The limb scattering profiler instrument has heritage from the two Shuttle Ozone Limb Sounding Experiment (SOLSE)/Limb Ozone Retrieval Experiment (LORE) shuttle demonstration flights in 1997 (STS-87) and 2003 (STS-107). These missions were developed by our Laboratory with partial support by the IPO. Data from these experimental flights are being used by Laboratory staff personnel to characterize the OMPS instrument and algorithm.

Laboratory scientists continue to support the IPO through the OOAT and the NPP mission science team. Laboratory scientists are conducting algorithm research, advising on pre- and postlaunch calibration procedures, and providing recommendations for validation. They participate in reviews for the OMPS instrument contractor

and the NPOESS system integrator. The Laboratory staff members are also assessing OMPS data for climate research. An algorithm has been developed to analyze the SAGE III data when SAGE III operates in a limb scattering mode, which will simulate retrievals expected from the OMPS profiler. This work is an extension of the retrievals used for the SOLSE-1 and SOLSE-2 missions. The advanced ultraviolet and visible radiative transfer models developed in the Laboratory over the last two decades enable this research. The two decades of experience in TOMS and SBUV calibration and validation will also be applied to OMPS. For more information, contact Richard McPeters (Richard.D.McPeters@nasa.gov).

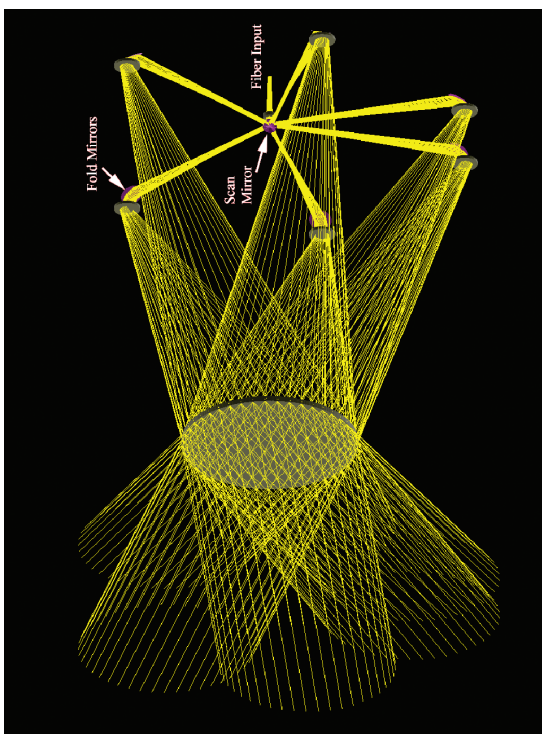
Holographic Scanning Lidar Telescope Technology

Some lidar remote sensing applications require scanning a large aperture telescope over widely separated fields of view in rapid succession. Conical scanning telescopes that use a Holographic Optical Element (HOE) for their primary optic are being developed to reduce the size, weight, angular momentum, and costs associated with this type of scanning using conventional optical telescopes. Building on our prior successes in developing ground-based and airborne lidar systems using large rotating HOEs in the visible and 1 μm wavelength regions, we are now pushing this technology into the ultraviolet and 2 μm wavelength regions.

The first two lidars using HOE technology are the Prototype Holographic Atmospheric Scanner for Environmental Remote Sensing (PHASERS) and HARLIE. PHASERS is a ground-based lidar using a 532 nm laser, and is now operated by Dr. David Guerra of the Physics Dept. at Saint Anselm College in Manchester, NH. HARLIE is a 1 μm wavelength backscatter lidar operated by GSFC. It is currently being modified for use at a wavelength of 355 nm and interfaced to a Doppler receiver for the first ground-based demonstration of atmospheric Doppler wind measurements using HOE technology. PHASERS and HARLIE have proven the utility of using HOEs as lidar receivers and demonstrated a factor of 3 reduction in the weight of the telescope/scanner assembly compared to conventional technology.

As part of their Instrument Incubator Program (IIP), ESTO is funding the development of a high-altitude airborne Doppler wind lidar that will use a 40 cm diameter rotating HOE telescope operating with a 355 nm laser transmitter called the Tropospheric Wind Lidar Instrument Technology Experiment (TWiLiTE), described previously in this report.

Figure 4.5. Illustration of how a ShADOE is used to multiplex six narrow fields of view into a single receiver system. Mechanical structures have been omitted for clarity; only the optical components and the ray paths are shown. The ShADOE is the large circular optic near the bottom, focusing light from each field of view to secondary optics located in a circle above. These direct the light to a centrally located small rotating scanner that feeds each beam in sequence into a common fiber optic.



ESTO also began funding for the development of a Shared Aperture Diffractive Optical Element (ShADOE) telescope, under their Advanced Component Technology program. The ShADOE telescope will eliminate most or all mechanical moving components by sequentially “addressing” several holograms multiplexed into a single optic in order to scan over the multiple fields of view. This last development should reduce the weight of large aperture scanning receivers by another factor of three. The objectives of the ShADOE project follow:

- Enable atmospheric Doppler (e.g., wind profiling) and surface mapping lidar applications from space;
- Develop diffraction-limited holographic, or diffractive optical, elements for use with 2054 nm wavelength lasers and near-diffraction limited ShADOEs for use at 355 nm;
- Demonstrate an angle-multiplexed, multi-wavelength ShADOE telescope suitable for use with single and dual-wavelength lidars; and
- Advance the ShADOE technical readiness level (TRL) from 2 to 4.

Starting from a Director’s Discretionary Fund (DDF) program in the early 1990s, this program is leveraged by prior and current investments by the NASA Small Business Innovation Research Program (SBIR) program, the Cross-Cutting Technology Program, and the GSFC Independent Research and Development (IRAD) and Core Competency programs. The IPO also supports the development of this technology as a risk reduction for lidar applications on NPOESS, including direct detection wind lidar systems. For more information on this technology, visit the Web site at <http://harlie.gsfc.nasa.gov/>, or contact Bruce Gentry (Bruce.M.Gentry@nasa.gov).

Tropospheric Wind Profile Measurements

Measurements of tropospheric wind profiles from ground, air, and spaceborne platforms are important for understanding atmospheric dynamics on a variety of time scales. Numerous studies have shown that direct measurement of global winds will greatly improve numerical weather prediction. Because of this importance, the operational weather forecasting communities have identified global tropospheric winds as the number one unmet measurement requirement in the Integrated Operational Requirements Document (IORD-1) for NPOESS, the next generation polar orbiting weather satellite. The Laboratory is using these requirements to develop new Direct Detection Doppler Lidar technologies and systems to measure tropospheric wind profiles, first from the ground and on high altitude aircraft, and then from satellites. Ground-based (see GLOW) and airborne (see TWiLiTE) Doppler lidar systems provide critical validation of new technologies proposed for eventual spaceborne operation. ESTO and the NPOESS IPO are supporting the effort. For more information, contact Bruce Gentry (Bruce.M.Gentry@nasa.gov).

Tropospheric Wind Lidar Technology Experiment (TWiLiTE)

Global measurement of tropospheric winds is a key measurement for understanding atmospheric dynamics and improving numerical weather prediction. Global wind profiles remain a high priority for the operational weather community and also for a variety of research applications including studies of the global hydrologic cycle and transport studies of aerosols and trace species. In addition to space-based winds, a high altitude airborne system flown on UAV or other advanced platforms would be of great interest for studying mesoscale dynamics and hurricanes. The TWiLiTE project was selected in 2005 by ESTO as part of the IIP. TWiLiTE will leverage significant research and development investments in key technologies made in the past several years. The primary focus will be on integrating these subsystems into a complete molecular direct detection Doppler wind lidar system designed for autonomous operation on a high-altitude aircraft, such as the NASA WB-57, so that the nadir-viewing lidar will be able to profile winds through the full troposphere.

TWiLiTE is a collaboration involving scientists and technologists from NASA Goddard, the NOAA Earth System Research Laboratory (ESRL), Utah State University Space Dynamics Lab, and industry partners Michigan Aerospace Corporation and Sigma Space Corporation. NASA Goddard and its partners have been at the forefront in

the development of key lidar technologies (lasers, telescopes, scanning systems, detectors, and receivers) required to enable spaceborne global wind lidar measurement. The TWiLiTE integrated airborne Doppler lidar instrument will be the first demonstration of a airborne scanning direct detection Doppler lidar and will serve as a critical milestone on the path to a future spaceborne tropospheric wind system. For more information, contact Bruce Gentry (Bruce.M.Gentry@nasa.gov).

4.7 Project Scientists

Spaceflight missions at NASA depend on cooperation between two upper-level managers—the project scientist and the project manager—who are the principal leaders of the project. The project scientist provides continuous scientific guidance to the project manager while simultaneously leading a science team and acting as the interface between the project and the scientific community at large. Table 4.2 lists the project- and deputy project scientists for current missions; Table 4.3 lists the validation and mission scientists for various campaigns.

Table 4.2: Laboratory for Atmospheres project and deputy project scientists.

Project Scientists		Mission and Deputy Project Scientists	
Name	Project	Name	Project
Robert Adler	TRMM	Anne Douglass	EOS Aura, UARS
Pawan K. Bhartia	TOMS	Ernest Hilsenrath	EOS Aura
Robert Cahalan	EOS SORCE	Gerald Heymsfield	TCSP
Dennis Chesters	GOES	Hans Mayr	AIM
James Gleason	NPP	Matt McGill	CALIPSO
Jay Herman	DSCOVR	Matt McGill	CloudSat
Charles Jackman	UARS	Steve Platnick	EOS Aqua
Eric Smith	GPM	Marshall Shepherd	GPM
Joel Susskind	POES	Si-Chee Tsay	EOS Terra
		Warren Wiscombe	ARM, Chief Scientist

Table 4.3: Laboratory for Atmospheres campaigns and mission scientists.

EOS Validation Scientist		Field/Aircraft Campaigns	
Name	Mission	Name	Campaign
David Starr	EOS	Paul Newman	AVE
		Si-Chee Tsay	UAE ²
		Si-Chee Tsay	BASE-ASIA
		Judd Welton	MPLNET

4.8 Interactions with Other Scientific Groups

Interactions with the Academic Community

The Laboratory relies on collaboration with university scientists to achieve its goals. Such relationships make optimum use of government facilities and capabilities and those of academic institutions. These relationships also promote the education of new generations of scientists and engineers. Educational programs include summer programs for faculty and students, fellowships for graduate research, and associateships for postdoctoral studies. A number of Laboratory members teach courses at nearby universities and give lectures and seminars at U.S. and foreign universities. (See Section 6 for more details on the education and outreach activities of our Laboratory.) The Laboratory frequently supports workshops on a wide range of scientific topics of interest to the academic community.

NASA and non-NASA scientists work together on NASA missions, experiments, and instrument and system development. Similarly, several Laboratory scientists work on programs residing at universities or other Federal agencies.

The Laboratory routinely makes its facilities, large data sets, and software available to the outside community. The list of refereed publications, presented in Appendix 2, reflects our many scientific interactions with the outside community; over 85% of the publications involve coauthors from institutions outside the Laboratory.

A prime example of the collaboration between the academic community and the Laboratory is given in this list of collaborative relationships via Memoranda of Understanding or cooperative agreements:

- Cooperative Institute of Meteorological Satellite Studies (CIMSS) with the University of Wisconsin, Madison;
- ESSIC, with the University of Maryland, College Park;
- GEST Center, with the University of Maryland, Baltimore County (and involving Howard University);
- JCET, with the University of Maryland, Baltimore County; and
- Joint Center for Observation System Science (JCOS) with the Scripps Institution of Oceanography, University of California, San Diego.
- Cooperative agreement with Colorado State University, Fort Collins, CO.

These collaborative relationships have been organized to increase scientific interactions between the Laboratory for Atmospheres at GSFC, and the faculty and students at the participating universities.

In addition, university and other outside scientists visit the Laboratory for periods ranging from one day, to as long as two years. Some of these appointments are supported by Resident Research Associateships offered by the National Research Council (NRC) of the National Academy of Sciences; others, by the Visiting Scientists and Visiting Fellows Programs currently managed by the GEST Center. Visiting Scientists are appointed for up to two years and perform research in pre-established areas. Visiting Fellows are appointed for up to one year and are free to carry out research projects of their own design.

Interactions with Other NASA Centers and Federal Laboratories

The Laboratory maintains strong, productive interactions with other NASA Centers and Federal laboratories.

Our ties with the other NASA Centers broaden our knowledge base. They allow us to complement each other's strengths, thus increasing our competitiveness while minimizing duplication of effort. They also increase our ability to reach the Agency's scientific objectives.

Our interactions with other Federal laboratories enhance the value of research funded by NASA. These interactions are particularly strong in ozone and radiation research, data assimilation studies, water vapor and aerosol measurements, ground-truth activities for satellite missions, and operational satellites. An example of interagency interaction is the NASA/NOAA/National Science Foundation (NSF) Joint Center for Satellite Data Assimilation (JCSDA), which is building on prior collaborations between NASA and NCEP to exploit the assimilation of satellite data for both operational and research purposes.

Interactions with Foreign Agencies

The Laboratory has cooperated in several ongoing programs with non-U.S. space agencies. These programs involve many of the Laboratory scientists.

Major efforts include the Tropical Rainfall Measuring Mission (TRMM), with the Japanese National Space Development Agency (NASDA); the TOMS Program, with NASDA and the Russian Scientific Research Institute of Electromechanics (NIEM); the Neutral Mass Spectrometer (NMS) instrument, with the Japanese Institute of Space and Aeronautical Science (ISAS); and climate research with various institutes in Europe, South America, Africa, and Asia. Another example of international collaboration was in the SOLVE II (SAGE III Ozone Loss and Validation Experiment) campaign, which was conducted in close collaboration with the Validation of International Satellites and study of Ozone Loss (VINTERSOL) campaign sponsored by the European Commission. More than 350 scientists from the United States, the European Union, Canada, Iceland, Japan, Norway, Poland, Russia, and Switzerland participated in this joint effort, which took place in January 2003. In 2004, another international collaboration started with the upload of instruments for the Polar Aura Validation Experiment (PAVE). PAVE is an Aura satellite validation involving instruments on the DC-8. Many of the experimenters from SOLVE II are involved in this campaign, which took place in late January and early February of 2005.

Laboratory scientists interact with about 20 foreign agencies, about an equal number of foreign universities, and several foreign companies. The collaborations vary from extended visits for joint missions, to brief visits for giving seminars, or working on joint science papers.

4.9 Commercialization and Technology Transfer

The Laboratory for Atmospheres fully supports Government–Industry partnerships, SBIR projects, and technology transfer activities. Successful technology transfer has occurred on a number of programs in the past and new opportunities will become available in the future. Past examples include the MPL, holographic optical scanner technology, and Circle to Point Conversion Detector. New research proposals involving technology development will have strong commercial partnerships wherever possible.